Chapter 5
Ground Control Requirements for Photogrammetric Mapping

5-1. General

This chapter covers ground control requirements for photogrammetric mapping projects. The fundamental requirements for control network configuration, point location, and image characteristics are discussed. However, the overview presented here is not intended to be used for field survey design or survey procedural instruction. The USACE specification writer or photogrammetric engineer should refer to appropriate survey standards and specifications for guidance in designing the project control surveys.

5-2. Coordinate Reference Systems

The coordinate reference system is the backbone of a mapping project. It provides the framework to tie together all field survey and map data. The coordinate reference system must be specified for the final map product. Typically, the State Plane Coordinate zone or the universal transverse Mercator (UTM) zone in which the project is located is used to define a mapping coordinate system. The photogrammetric engineer must be familiar with the reference datum, the coordinate system definition, and the methods required to transform all data into the final map coordinate system. Chapter 10 reviews the definitions of the datums and coordinate systems typically encountered in mapping. Several sources in Appendix A provide detailed information on datums, coordinate systems, and map projections.

5-3. Ground Control Requirements for Photogrammetric Mapping

Field surveying for photogrammetric control is generally a two-step process. The first step consists of establishing a network of *basic control* in the project area. This basic control consists of horizontal control monuments and benchmarks of vertical control that will serve as a reference framework for subsequent surveys. The second step involves establishing *photo control* by means of surveys originating from the basic control network. Photo control points are the actual points appearing in the photos that are used to control photogrammetric operations. The accuracy of basic control surveys is generally of higher order than subsequent photo control surveys.

a. Basic control. A basic control survey provides a fundamental framework of control for all project-related surveys, such as property surveys, photo control surveys, location and design surveys, and construction layout. The accuracy, location, and density of the basic control must be designed to satisfy all the project tasks that will be referenced to the control. Horizontal basic control typically consists of linear traverse lines or trilaterated networks connecting horizontal points. Vertical basic control is typically a separate survey of level routes and route networks connecting vertical points.

(1) Horizontal basic control points should be angle points in traverses or vertices of network triangles. Vertical basic control points should be turning points in level routes. Side shots or open traverses should not be used to locate basic control. Second- or Third-Order plane surveys will generally be of sufficient accuracy to establish basic control for most, if not all, USACE projects. See also the guidance in Table 2-4.

(2) In planning the basic control survey, maximum advantage should be taken of existing, or project, control established in the area by the USACE Command. In remote areas, basic control may have been established by the National Geodetic Survey (NGS) or USGS. In many locations, local control points exist such as those established for State agency and urban area networks. Care should be exercised before using any control points to verify that they are adequately interconnected or are adequately connected to the national network (i.e., NGRS).

(3) Basic control survey stations should be located and monumented to be permanent, at least for the lifetime of the project. All stations should be fully described and referenced to permanent field reference points. The station descriptions should be included in the control survey report.

b. Photo control. Photo control points are photoidentifiable points that can be measured on the photograph and stereomodel. Photo control points are connected to the basic control framework by short spur traverses, intersections, and short level loops. Lengthy side shots and open traverses should be avoided. Photo control surveys are local surveys of limited extent. Photo control points are surveyed to the accuracy required to control the photogrammetric solution. Typically, Third-Order, Class II type plane surveys are sufficient to establish photo control points.

(1) Characteristics. Photo control points should be designed by considering the following characteristics: location of the control point on the photograph; positive identification of the image point; and measurement characteristics of the image point.

(a) Location. Of the characteristics listed in (1) above, location is always the overriding factor. Photo control points must be in the proper geometric location to accurately reference the photogrammetric solution to the ground coordinate system. Horizontal photo control points should define a long line across the photographic coverage. The horizontal control accurately fixes the scale and azimuth of the solution. Vertical photo control should define a geometrically strong horizontal triangle spanning the photographic coverage. The vertical control accurately fixes the elevation datum of the solution.

(b) Identification. The identification of the photo control points on the aerial photographs is critical. Extreme care should be exercised to make this identification accurate. The surveyor should examine the photo control point in the field using a small pocket stereoscope with the aerial photographs. Once a photo control point is identified, its position on the photograph should be pricked using a sharp needle. A brief description and sketch of each point should be made on the reverse side of the photograph. Each photo control point should be given a unique name or number.

(c) Measurement. Subject to the constraints imposed by location considerations, photo control points should be designed to provide accurate pointing characteristics during photogrammetric measurements. Furthermore, control points should not be located at the edge of the image format since image resolution and distortion are both degraded at the edge of the format. Photo control points falling in the outside 10 to 15 percent of the image format should be rejected.

(2) Horizontal photo control. Images for horizontal control have slightly different requirements from images for vertical control. Because their horizontal positions on the photographs must be precisely measured, images of horizontal control points must be very sharp and well defined horizontally. Care should be exercised to ensure that control points do not fall in shadowed areas.

(3) Vertical photo control. Images for vertical control need not be so sharp and well defined horizontally. Points selected should, however, be well defined vertically. Since meausurements are typically made stereoscopically, good vertical control points should have characteristics that make it easy for the operator to accurately put the floating mark at the correct elevation. Vertical control points are best located in small, flat or slightly crowned areas with some natural features nearby that assist with stereoscopic depth perception.

c. Control point distribution. The number of control points required and their optimum locations depend upon the use that will be made of them. For example, a semicontrolled mosaic may require only a sparse uniformly distributed network of horizontal control. The most demanding requirements for photo control are encountered when spatially resecting a photo or scaling and leveling a stereomodel.

(1) If photo control is being established for the purpose of orienting stereomodels in a plotting instrument for topographic map compilation, the absolute geometric minimum amount of photo control needed in each stereomodel is three vertical and two horizontal control points. However, some amount of redundant control should be used as a check. Thus, as a practical minimum, each stereomodel oriented in a plotter should have three horizontal and four vertical control points. The horizontal points should be widely spaced. Horizontal points in opposite diagonal corners of the neat model are optimum. Vertical control points should be in the corners of the neat model. Vertical control should never be along a single line in the neat model. A fifth vertical control point in the center of each stereomodel is useful as a quality control check for stereomodel deformation.

(2) Table 5-1 summarizes the number of photo control points required for typical photogrammetric products.

5-4. Marking Photo Control

Photoidentifiable control points can be established by marking points with targets before the flight or by selecting identifiable image points after the flight.

a. Premarking. Premarking photo control points is recommended for Class 1 and Class 2 mapping. Marking control points with targets before the flight is the most reliable and accurate way to establish photo control points. Survey points in the basic control network can also be targeted to make them photoidentifiable. When the terrain is relatively featureless, targeting will always produce a well-defined image in the proper location. However, premarking is also a significant

Table 5-1
Photo Control Required for Photogrammetric Products

Product	Minimum Control Required: Horizontal	Minimum Control Required: Vertical	Per Unit
Photo Enlargement	0	0	Photo
Rectified Photo (Controlled or Semicontrolled)	3 Total Control	0	Photo
Photo Plans and Mosaics	3	0	Sheet
Planimetric and Topographic Mapping	3	4	Stereomodel
Orthophoto Mapping	3	4	Stereomodel

expense in the project because target materials must be purchased, and targets must be placed in the field and maintained until flying is completed. The target itself should be designed to produce the best possible photo control image point. The main elements in target design are good color contrast, a symmetrical target that can be centered over the control point, and a target size that yields a satisfactory image on the resulting photographs.

(1) Location. Target location should be designed according to the characteristics for photo control points discussed in paragraph 5-3b. The optimum location for photo control points is in the triple overlap area; however, when control is premarked, it is difficult to ensure that the target will fall in the center of the triple overlap area when the photography is flown. Care should be taken that targets are not located too near the edge of the strip coverage so that the target does not fall outside of the neat model.

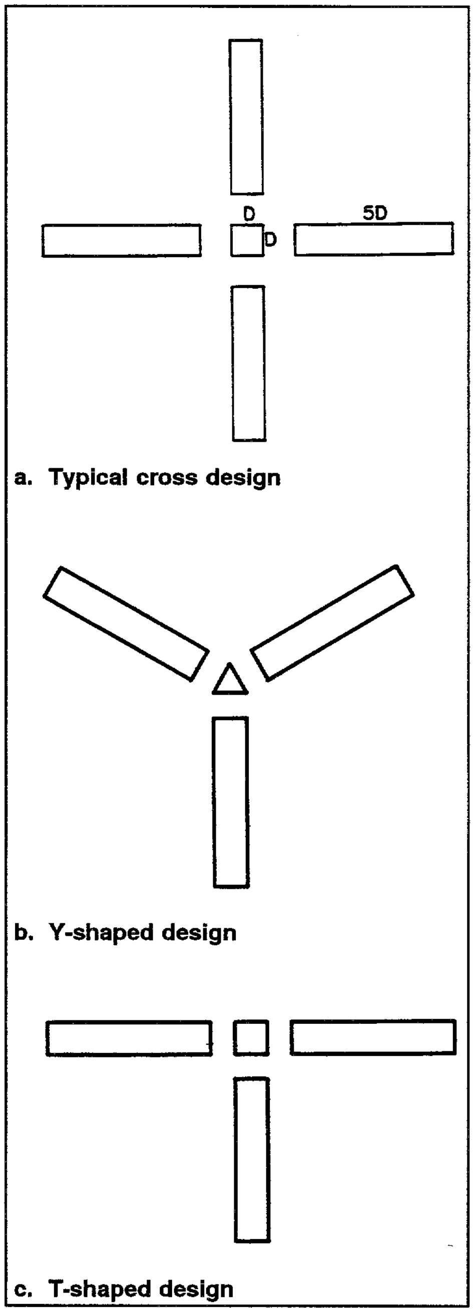
(2) Material. Targets may be made of cloth or plastic or may be painted on plywood, fiberboard, or similar sheet material or on pavement or flat rock outcrops. Flexible targets may be made by assembling pieces of the material to form the pattern or by printing the pattern on sheet material. Cloth, paint, and other material used for targets should have a non-glossy matte surface. Targets should be held in place by spikes, stakes, small sandbags, or any other means necessary to keep them in position and maintain flatness.

(3) Shape. Targets should be symmetrical in design to aid the operator in pointing on the control point. A typical cross design suggested by Wolf (1983) is illustrated in Figure 5-1. Similar leg and center panel designs can be developed in Y, T, and V shapes if field conditions require alternate shapes. The center panel should be centered over the control point, since this is the image point at which measurements will be taken. The legs help in identifying the targets on the photos and also in determining the exact center of the target should the image of the center panel be unclear.

(4) Size. Target sizes should be designed on the basis of intended photo scale so that the target images are the optimum size for pointing on the photos. Target size is related to the size of the measuring mark in the comparator and stereoplotter instruments used. An image size of about 0.050 mm square for the central panel is a typical design value. As shown in Figure 5-1, if the ground dimension of the central panel of the target is *D*, then the leg width should also be *D*, leg length should be 5*D*, and the open space between the central panel and the leg should be *D*. Target sizes are readily calculated once photo scale and optimum target image size are selected. If, for example, a central panel size of 0.050 mm is desired and photography at a scale of 1:12,000 is planned, then *D* should be 2.0 ft.

(5) Maintenance. All targets should be maintained in place and protected from or restored after damage by man, animals, or weather until photography has been taken. As soon as feasible after photography has been taken, each target should be inspected. If the inspection reveals that the target has been moved from its proper position or otherwise disturbed in any way, this fact should be reported in the photo control survey report. Damaged or lost targets will require that the photography on which the targets should appear be replaced with a new flight if the lost targets will jeopardize meeting the accuracy requirement for the photogrammetric product. As an alternative to replacing or relocating lost targets and replacing the deficient photography, unless the photography will be used for Class 1 mapping aerotriangulation, it may be permissible to substitute natural images for the lost targets when acceptable natural images are present and suitably located to replace all lost targets.

b. Postmarking photo identifiable control. Postmarking photo control after the photography is flown is a method that may be used for Class 3 mapping. The postmarking method consists of examining the



a. Typical cross design

b. Y-shaped design

c. T-shaped design

Figure 5-1. Typical ground control target designs

photography after it is flown and choosing natural image features that most closely meet the characteristics for horizontal or vertical photo control points. The selected features are then located in the field and surveyed from the basic control monuments. One advantage of postmarking photo control points is that the control point can be chosen in the optimum location—the corners of neat models and in the triple overlap area. The principal disadvantage of postmarking is that the natural feature is not as well defined as a targeted survey monument either in the field or on the image.

5-5. Survey Accuracy Standards

Ground control should be established to a level of accuracy commensurate with that specified for the final map product (see Chapter 2). Careful planning and analysis of the basic control and photo control ground surveys should be performed by the contractor to ensure that sufficient accuracy will be obtained throughout the project area to meet map compilation and aerotriangulation criteria.

a. Accuracy required. Field surveys to establish project control should ideally originate from higher order control established by USACE, NGS, USGS, or local agencies. Field surveys should be designed for the lowest order survey that will meet project requirements, as specified in Table 2-4. As the accuracy standard increases, the cost of the survey will increase significantly. As a rule of thumb, the accuracy of the horizontal photo control should be twice the horizontal map accuracy to be produced, and the vertical photo control accuracy should be as accurate as the spot elevation accuracy to be produced. The accuracy of a given photo control point is the propagated error in the basic control survey points combined with the error contributed by the survey to connect to the photo control point.

b. USACE standards. USACE standards and guidelines for control surveys are presently under development. Until the USACE standards are available, the FGCC standards discussed in *c* below should be used to plan and execute the basic and photo control surveys for photogrammetric aerotriangulation and mapping.

c. FGCC standards. Standards and Specifications for Geodetic Control Networks (FGCC 1984) may be used to plan and execute the basic and photo control surveys for photogrammetric aerotriangulation and mapping. FGCC relative accuracy standards for horizontal and vertical control are shown in Tables 5-2 and 5-3. The FGCC document also gives procedural specifications for triangulation, trilateration, traversing, Global Positioning System (GPS) and Doppler positioning, photogrammetry, and leveling field survey methods. These specifications should be followed to ensure that the accuracy standard will be met.

Table 5-2
FGCC Horizontal Distance Accuracy Standards

Survey Classification	Minimum Distance Accuracy
First-Order	1:100,000
Second-Order, Class I	1:50,000
Second-Order, Class II	1:20,000
Third-Order, Class I	1:10,000
Third-Order, Class II	1: 5,000

Table 5-3
FGCC Elevation Accuracy Standards

Survey Classification	Maximum Elevation Difference Accuracy, mm/km
First-Order, Class I	0.5
First-Order, Class II	0.7
Second-Order, Class I	1.0
Second-Order, Class II	1.3
Third-Order	2.0

The distance accuracy *1*:*a* is defined to be

$$a = \frac{d}{s} \tag{5-1}$$

where

a = distance accuracy denominator

d = distance between survey points

s = propagated standard deviation of distance between survey points obtained from a weighted and minimally constrained least squares adjustment

The elevation difference accuracy *b* is a ratio defined as

$$b = \frac{s}{\sqrt{d}} \tag{5-2}$$

where

b = elevation difference accuracy ratio

s = propagated standard deviation of elevation difference in millimeters between survey points obtained from a weighted and minimally constrained least squares adjustment

d = distance between control points in kilometers measured along the level route

5-6. Deliverables

Unless otherwise modified by the contract specifications, the following materials will be delivered to the Government upon completion of the control surveys:

a. General report describing the project and survey procedures used including description of the project area, location, and existing control found; description of the basic and photo control survey network geometry; description of the survey instruments and field methods used; description of the survey adjustment method and results such as closures and precision of adjusted positions; justification for any survey points omitted from the final adjusted network.

b. One set of paper prints showing all control points. The points should be symbolized and named on the image side, and the exact point location should be pinpricked through the print.

c. A list of the adjusted coordinates of all horizontal and vertical basic and photo control points.